SURVEY OF CONTAMINANTS IN SEDIMENTS AND FISH ON THE MINNESOTA VALLEY NATIONAL WILDLIFE REFUGE

by

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LIST OF TABLES

LIST OF FIGURES

ABSTRACT

In 1988, a survey of contaminants in sediments and/or fish from three waterbodies on the Minnesota Valley National Wildlife Refuge was undertaken. Sediment samples obtained from various locations on Long Meadow Lake were analyzed for heavy metals and polycyclic aromatic hydrocarbons (PAHs) to assess the nature and extent of urban stormwater discharge-related lakebed contamination. Fish obtained from Long Meadow Lake (common carp), Pond C (black bullheads, green sunfish) and Round Lake (black bullheads) were analyzed for heavy metals, organochlorine insecticides and total PCBs to assess their dietary human and wildlife health implications.

Various areas of Long Meadow Lake associated with stormwater outfalls were found to be moderately to grossly contaminated by PAHs and various metals (e.g., lead, copper, manganese, chromium, mercury, and zinc). Pond C bullhead fillets were found not to contain harmful levels of lead, as had been previously suspected. Whole common carp and black bullheads from Long Meadow and Round Lakes, respectively, were found to contain PCB concentrations which exceeded Minnesota's lowest (one meal per week) consumption advisory. Additional fish collections from those lakes for analysis of skin-on fillets was advised in the event that fishing for consumptive purposes was an ongoing activity. Adverse reproductive effects to mink and bald eagles as a result of feeding on fish from either lake was judged unlikely. Several recommendations for additional studies and management actions are offered.

TABLE OF CONTENTS

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INTRODUCTION

Long Meadow Lake on the Minnesota Valley National Wildlife Refuge (Figure 1) is an important breeding and stopover area for mallards, wood ducks and other migratory waterfowl, wading birds and shorebirds. Refuge staff has been concerned for a number of years that contamination associated with stormwater discharges to the lake might be impairing its productivity to an increasing extent over time. A 1985 biological survey (Zischke and Cole 1987) found invertebrate densities in the lake slightly to significantly lower than in two other Upper Midwest wetland ecosystems and suggested disrupted aquatic vegetation communities and stormwater runoff as potential causes.

A contaminants survey conducted in 1985 identified an on-Refuge stormwater detention pond (Pond C) which had surface sediments moderately to heavily contaminated with heavy metals and polynuclear aromatic hydrocarbons (PAHs). Before discharging to Long Meadow Lake, Pond C receives stormwater runoff from nearly 2600 acres of fully developed residential, commercial and industrial property in the cities of Bloomington and Richfield, Minnesota. With only 147 acre-feet of stormwater storage above its normal pool elevation, the pond can provide detention for slightly less stormwater than that generated by a 4.2-inch (24-hour, 10-year) rainfall event over its watershed (City of Bloomington 1988). During the midpoint of a 2.3-inch (24-hour, one-year) storm event, removal of suspended solids and lead (a surrogate for other heavy metals) from the pond's discharge to Long Meadow Lake has been estimated to be only 63 and 47 percent, respectively. During such an event, the total estimated mass of lead escaping Pond C into Long Meadow Lake during the first 20 hours is 8.25 kilograms in an estimated total suspended solids concentration of 1450 parts per million (ibid).

Refuge staff also became concerned about the human health implications of eating fish taken from Long Meadow Lake, Pond C, and Round Lake (a small satellite Refuge Unit located about 20 miles north of the main Refuge in an urban/industrial setting). Black bullheads (*Ictalurus melas)* collected from Pond C in 1986 had whole body lead concentrations of 3.6-3.9 parts per million (ppm) on a wet weight basis, whereas the World Health Organization has recommended a maximum safe level of lead in the diet of adult humans of 0.3 ppm (WHO 1972). The present study was an attempt to preliminarily address aquatic invertebrate toxicity, human health and wildlife health issues through the collection and chemical analysis of nearshore and offshore Long Meadow

Lake bed sediments in the vicinity of several stormwater outfalls, and the collection and analysis of fish from the above-mentioned Refuge waters.

METHODS

Sediments

On August 5, 1988, sediment samples consisting of composites of three, 10-centimeter deep Eckman dredge grabs were obtained in pairs from the bed of Long Meadow Lake approximately 50, 150 and 250 feet lakeward of the Pond C outfall (Figure 2). On August 8 and 9, additional sediment samples were obtained from the beds of three small streams carrying stormwater to the lake and from varying distances offshore of three major stormwater outfalls to the lake (Figure 3, Table 1). Material from each composited sample was homogenized, placed in two chemically clean glass containers and frozen for shipment to analytical laboratories. Trace metals analyses were performed by Hazleton Laboratories, Madison, Wisconsin, and PAH analyses were performed by Mississippi State University, Starkville, Mississippi. Because previous sampling of these waterbodies had shown DDT and its metabolites, other organochlorine insecticides and total PCBs to be low or non-detectable in surficial sediments, that group of compounds was not analyzed for.

Fish

Because organochlorine insecticides and total PCBs in aquatic systems can biomagnify from less than Service-contracted analytical detection limits in sediments (0.01 and 0.05 ppm, respectively) to biologically significant concentrations in fish, it was judged worthwhile to analyze the fish from all three waterbodies for those compounds.

Six black bullhead whole fish composite samples, each consisting of five fish, were obtained by trapnet from Round Lake on August 17, 1988. Three composites were analyzed for organochlorines and total PCBs (Mississippi State) and three for trace metals (Hazleton). Black bullheads and green sunfish (*Lepomis cyanellus)* obtained from Pond C by trapnet and gillnet were filleted, skinned, washed, composited by species and frozen for analysis of organochlorines/total PCBs (six samples) and trace metals (three samples). Two Long Meadow Lake common carp (*Cyprinus carpio)* captured by gillnet were submitted as individual samples for organochlorine and total PCB analyses.

RESULTS

Sediments

Results of the analyses of 19 sediment samples for trace metals and total PAHs are presented in Table 2. Table 3 provides two commonly used trace metal and organic compound concentration guidelines for the evaluation of sediment-sorbed contaminants (Long and Morgan 1990, Persaud et al. 1990). Exceedance of the more conservative of either "lowest effect" level for a particular contaminant identified in those guidelines suggests that sensitive benthic invertebrates at a given sample site may be experiencing toxicity-related adverse impacts from the contaminant in question. Neither guideline attempts to address the effects of multiple contaminant additivity, synergism or antagonism.

A comparison of Tables 2 and 3 shows that all 19 sediment samples exceeded the "lowest effect" level for sediment-sorbed copper (Cu), manganese (Mn) and lead (Pb). Numerous samples also equalled or exceeded the most conservative "lowest effect" level for chromium (Cr; 5 samples), mercury (Hg; 4 samples), zinc (Zn; 13 samples) and total PAHs (14 samples). Samples collected near the Pond C outfall exceeded "lowest effect" levels for lead (all samples), copper (all samples), chromium (5 of 6 samples), manganese (all samples), zinc (all samples) and total PAHs (all samples).

Fish

Contaminant residues in fish from the three Refuge waters are presented in Table 4. It became immediately apparent that the detection limits for lead in the fish fillet samples from Pond C (2.0 ppm) were too high to be of value in assessing the potential human health hazard associated with eating fish from that pond. The analytical laboratory was told to re-analyze those specific samples using a methodology providing a lead detection limit of less than 0.3 ppm wet weight. Results of the re-analysis showed that Pond C black bullhead fillets contained non-detectable lead residues at a revised detection limit of 0.1 ppm.

To put the Round Lake whole fish (black bullhead) residue data into perspective, those data were compared, where possible, to the most recent geometric mean contaminant residue results for multiple fish species reported for the National Contaminant Biomonitoring Program (NCBP) for 1984 (Schmitt and Brumbaugh. 1990, Schmitt,et al. 1990). Unfortunately, the only analytes in common were cadmium, copper, lead, zinc, total PCBs, DDT, DDD, and DDE. Of that list, only cadmium, copper, total PCBs, DDD and DDE concentrations in the Round Lake fish were above method detection limits and, thus, available for comparison. Metals residues in those fish were also compared to those in bluegills (*Lepomis macrochirus)* obtained during a 1985 survey of Pools 4 through 10 on the Upper Mississippi River (Mahaffy et al. 1991).

CONCLUSIONS

Sediments

All areas from which sediment samples were obtained showed some degree of contamination by urban stormwater runoff constituents (e.g., lead, copper, zinc and total PAHs). By far, the worst in that regard was the Pond C outfall to Long Meadow Lake, where samples collected up to several hundred feet lakeward of the outfall were grossly contaminated with trace metals and total PAHs. Within that zone and perhaps beyond, one could expect benthic invertebrate diversity to be severely diminished or absent. A broad nearshore area in the west arm of the lake extending lakeward of 36-inch and 48-inch stormwater outfalls (Figure 2) also shows substantial sediment contamination due to stormwater runoff (samples 14-16). In that area, impacts to resident aquatic invertebrate diversity and abundance would probably be less severe than within the Pond C outfall area, but still apparent. The value of either of the above two areas for aquatic invertebrate production, thus, migratory bird food resources, could be moderately-to-severely diminished.

Based on the analytical results for samples 18 and 19, offshore areas of the lake appear to be considerably less affected by, though not free of, stormwater runoff contamination. Disregarding lead, for which analytical detection limits were not sufficiently low, sediment concentrations of the other typical urban stormwater runoff constituents may not be high enough to impair the health of mid-lake aquatic invertebrates. However, if either synergism or additivity of toxic effects is operative among the contaminants in question, even mid-lake sediments may constitute an unhealthy environment for the more sensitive benthic invertebrate taxa.

Fish

Metals

Upon re-analysis, skin-off fillets for Pond C black bullheads were found to contain less than 0.1 ppm lead and did not, therefore, represent a threat to human health. Much of the lead previously detected in whole bullheads from the pond had apparently been associated with body slime and gut contents. We were unable to locate skin-off fillet metals concentration data in the literature for comparison purposes. Regarding the single elevated aluminum concentration (4.4 ppm) for skin-off sample #3, all fish samples were wrapped in aluminum foil for shipment to analytical laboratories. It is likely that a piece of aluminum foil remained attached to that particular sample as it was prepared for analysis.

With the exception of copper, trace metal concentrations above analytical detection limits in Round Lake whole bullhead composite samples were comparable to, or less than, metal concentrations found in bluegills taken from Pools 4 through 10 on the Upper Mississippi River in 1985 (Mahaffy et al. 1991) and geometric mean concentrations for those respective metals reported for the 1984 NCBP. On a wet weight basis, Round Lake whole bullhead composite samples contained 0.8-1.5 ppm copper, whereas Mississippi River whole bluegill copper concentrations ranged from 0.3-0.8 ppm and the NCBP geometric mean copper concentration for multiple fish species was 0.65 ppm. There is reason to believe that the elevated copper concentrations reported for Round Lake bullheads were not the result of analytical error. Copper was a contaminant present in the Twin City Army Ammunition Plant industrial discharge to Round Lake prior to 1970 and has been found in high concentrations in lake sediments around the discharge outfall at the north end of the lake. Though the soluble form of copper can be toxic to plants and invertebrates at relatively low concentrations in water, it is also an essential dietary element for both. At the above-reported tissue concentrations, it is probably not harmful to fish and is not biomagnified to any significant extent in higher trophic level fish consumers, including humans (Hutchinson et al. 1976). The toxic and bioaccumulative effects of copper, other metals and PCBs in Round Lake sediments are being further evaluated as part of the Off-Site Remedial Investigation for the TCAAP "Superfund" site.

Organic Compounds

The contaminant-related threat to humans and wildlife health from eating common carp from Long Meadow Lake is difficult to determine with any degree of certainty due to the fact that only two mature fish of similar size were obtained for PCB analysis. One of those contained approximately 1.0 ppm total PCBs while the other was reported to contain less than 0.050 ppm (the minimum method detection limit). A possible explanation for this large variance is that the fish with no detectable PCBs may have spent most or all of its life in Long Meadow Lake, where previous sampling has found PCB contamination to be low or not measurable, while the PCB-contaminated fish may have entered the lake relatively recently after spending much of its life in the more PCB-contaminated Minnesota River/Mississippi River system. A more comprehensive survey of Long Meadow Lake fish PCB residues would be necessary to develop a reasonable size-related estimate of "average" PCB concentrations in carp or other species.

The "lowest observable adverse effect level" (LOAEL) for total PCBs in the diets of ranch mink - a reasonable substitute for wild mink (*Mustela vison*) - has been estimated to be in the range of 0.30 - 0.64 ppm (Platanow and Karstad 1973, U.S.EPA 1993, Kubiak and Best 1991, Ludwig et al. 1993). Within and above that concentration range, reproductive failure, mortality, and decreased kit survival can occur. Bald eagles (*Haliaeetus leucocephalus*) have been found to be even more sensitive to PCB contamination of their food source than mink, in part because eagles also occasionally feed on piscivorous waterbirds such as gulls and cormorants which have also concentrated persistent PCB fractions in their tissues while feeding on the same prey base. Consequently, the LOAEL for total PCBs in bald eagle fish prey has been estimated to be 0.067 ppm (Kubiak and Best 1991). Whether wild mink or bald eagles eating Long Meadow Lake fish would experience reproductive problems would depend upon the relative portions of their diets consisting of non-fish items (e.g., amphibians, birds, terrestrial rodents, muskrats), the contributions to their diets of fish obtained from other more or less PCB-contaminated waters, the species and sizes of fish typically captured, and average PCB concentrations in those "typical" fish prey. While very little of the above information is available for the Long Meadow Lake ecosystem, it is clear that a diet comprised exclusively of fish in the lake having detectable (i.e., greater than 0.050 ppm wet weight) PCB concentrations in their tissues may cause reproductive problems for both mink and bald eagles.

Human health consequences of eating fish from Long Meadow Lake also cannot be addressed by this survey. Minnesota's lowest human consumption advisory is one meal per week of fish whose skin-off fillets contain 0.025-0.10 ppm total PCBs. Whole body PCB concentration data for one size class of one species is insufficient to predict whether skin-off fillets for any size class of any fish species would or would not trigger the consumption advisory. If fish are known to be routinely taken from the lake for human consumption, a sampling strategy based on the Minnesota Health Department's consumption advisory could be developed which would determine whether any size class of the relevant fish species deserves consumption advisory status.

The three Round Lake whole bullhead composite samples were found to contain total PCBs at concentrations ranging from 0.16 - 0.27 ppm. To our knowledge, black bullheads are the only gamefish species in the lake. Fish in each of the three composites ranged from eight to nine inches in length and were representative of the largest fish in the lake as well as the size of fish that would be most likely to be kept by fishermen. Assuming that an estimated 75 percent of the PCB content of black bullheads is associated with organs and lipids (fat) in the body cavity and, thus, would be removed during the filleting process, 0.04 to 0.06 ppm total PCBs would remain with the "edible portion" represented by the three composite samples. Therefore, mature Round Lake black bullheads could fall within the one meal per week consumption advisory. Additional work would be necessary to determine more precisely the amount of PCBs removed by the filleting process before instituting a fish consumption advisory for Round Lake.

A diet of exclusively Round Lake black bullheads would not likely cause PCB-related adverse reproductive effects in wild mink, based on the best information currently available. Also, due to its isolated nature in a densely urban setting, it is doubtful that Round lake is visited often, if ever, by mink. Bald eagles would be only slightly more likely to be adversely affected if their diets were exclusively Round Lake black bullheads and fish-eating birds for an extended period of time. The likelihood of the latter event occurring seems minimal.

DDE is a metabolite (breakdown product) of the long-banned insecticide, DDT, which has been shown to be responsible for eggshell thinning in fish-eating raptors. As little as 2.8 ppm DDE, wet weight, in the diets of American kestrels (*Falco sparverius)* has been shown to cause adverse reproductive effects related to possible egg breakage during laying and incubation (Wiemeyer and Porter 1970). At least partly because of their tendency to occasionally prey upon fish-eating birds, bald eagles are known to be susceptible to adverse reproductive effects at DDE dietary levels much lower than for kestrels. Kubiak and Best (1991) have estimated a LOAEL of 0.006 ppm wet weight DDE in fish prey of bald eagles in the Great Lakes. Because the highest Round Lake fish composite DDE concentration was 0.030 ppm, an eagle would need to obtain more than 20 percent of its annual dietary requirements from Round Lake bullheads in order to demonstrate an observable DDE-related reproductive effect. That event seems unlikely at the present time.

RECOMMENDATIONS

1. In order to make a persuasive case for the reduction or elimination of heavy metal and organic contaminants from Pond C watershed discharges to Long Meadow Lake, a comprehensive survey of sediment-associated contamination, its toxicity to aquatic invertebrates, and the diversity and abundance of resident aquatic invertebrates relative to other, less contaminated areas of the lake should be undertaken in the Pond C stormwater discharge zone.

2. If human consumption of Long Meadow Lake fish - in particular, common carp - is presently suspected to be occurring on a regular basis (> one meal per week) or is anticipated in the future, a statistically valid survey of PCBs in skin-on fillets of that and other relevant fish species should be undertaken in order to determine whether such consumption should be discouraged or modified.

3. The frequency with which bald eagles and other fish-eating raptors feed in Round and Long Meadow Lakes should be determined. If feeding is infrequent, no other action is necessary. In the less likely event that such feeding activity is judged to be frequent, continued whole fish contaminant residue monitoring ought to be undertaken on a more regular basis. Round Lake sediment remediation measures undertaken in conjunction with the TCAAP Superfund site cleanup may, with time, resolve that lake's problem with PCB-contaminated fish. The extent to which management options exist to effectively deal with potentially unacceptably high PCB residues in Long Meadow Lake fish should be considered.

4. If fishing pressure on Round Lake bullheads cannot be effectively controlled, an updated survey to determine the degree of human health risk associated with eating those fish ought to be undertaken. Following completion of such a survey, the appropriate consumption advice or warning ought to be conspicuously displayed at all access points to the lake.

TABLES

Table 1. Sampling Locations for Sediment Quality Study, Long Meadow Lake, Minnesota Valley National Wildlife Refuge, Minnesota, 1988 (also see Figure).

Site No.	Location
001	Pond C Outlet: 50 yards SW of outfall
002	" "": 50 yards SE of outfall
003	" ": 150 yards SW of outfall
004	" ": 150 yards SE of outfall
005	" ": 250 yards SW of outfall
006	" ": 250 yards SE of outfall
007	Downstream of 36" culvert west of Kelly Road
008	" " east of Kelly Road
009	Peterson Pond: West end
010	" ": East end
011	Orchard Springs outflow
012	18" culvert at west end of lake: 50' offshore
013	18" " ": 200' SE
014	36" " ": 40' offshore
015	36" " ": 150' SE
016	48" " ": 250' offshore
017	48" " ": 350' SE
018	48" " ": 900' east
019	East end of west arm of lake: mid-lake

Table 2. Trace metal and total PAH concentrations (ppm, dry weight) in sediment samples, Long Meadow Lake, Minnesota Valley National Wildlife Refuge, Minnesota, August, 1988.

Sample No.	Sb	Hg	Se	Tl	Al	Ba	Be	Bo
001	0.55	0.13	0.66	<0.33	5760.00	133.00	<1.66	20.20
002	0.96	0.28	1.70	<0.57	11000.00	202.00	<2.84	<28.40
003	0.94	0.15	1.60	<0.54	9460.00	180.00	<2.70	<27.00
004	0.88	<0.16	1.90	<0.65	12000.00	235.00	<3.23	<32.30
005	0.84	0.19	1.00	<0.52	11000.00	195.00	<2.62	<26.20
006	0.95	0.32	1.50	<0.50	12800.00	198.00	<2.49	<24.90
007	0.43	0.12	1.30	0.44	11300.00	157.00	<2.18	<21.80
008	0.50	<0.06	0.49	<0.24	6540.00	165.00	<1.22	<12.20
009	0.48	<0.16	1.30	<0.63	10900.00	147.00	<3.14	<31.40
010	0.38	<0.13	1.00	<0.51	10100.00	201.00	<2.53	<25.30
011	0.62	<0.13	1.60	<0.52	8480.00	225.00	<2.62	28.30
012	0.34	<0.17	1.40	<0.68	9110.00	153.00	<3.42	<34.20
013	0.53	<0.18	1.40	<0.72	12200.00	197.00	<3.60	<36.00
014	0.76	0.15	1.10	<0.56	9160.00	151.00	<2.79	<27.90
015	0.51	<0.14	1.10	<0.56	9660.00	160.00	<2.81	<28.10
016	0.49	<0.09	0.70	<0.35	9050.00	125.00	<1.75	<17.50
017	0.51	0.14	0.93	<0.46	8700.00	123.00	<2.31	<23.10
018	0.32	<0.10	0.80	<0.40	7870.00	126.00	<2.01	<20.10
019	0.47	<0.20	2.40	<0.81	9020.00	148.00	<4.06	<40.60

Table 2 (con't). Trace metal and total PAH concentrations (ppm, dry weight) in sediment samples, Long Meadow Lake, Minnesota Valley National Wildlife Refuge, Minnesota, August, 1988.

Sample No.	Cd	Cr	Cu	Fe	Pb	Mg	Mn	Mo
001	<1.66	19.20	48.70	13800.00	155.00	7810.00	738.00	<16.6
002	<2.84	41.50	94.30	20600.00	438.00	14300.00	920.00	<28.4
003	<2.70	31.40	90.30	19000.00	263.00	12600.00	1090.00	<27.0
004	<3.23	38.70	92.30	23700.00	363.00	14400.00	1250.00	<32.3
005	<2.62	35.60	85.90	20800.00	302.00	13100.00	922.00	<26.2
006	<2.49	39.80	82.10	21000.00	398.00	14200.00	751.00	<24.9
007	<2.18	26.20	69.40	23100.00	136.00	13200.00	1110.00	<21.8
008	<1.22	24.60	62.70	16100.00	83.40	10100.00	770.00	<12.2
009	<3.14	23.30	62.90	20700.00	<62.90	11300.00	660.00	<31.4
010	<2.53	20.70	57.60	20900.00	<50.50	10500.00	732.00	<25.3
011	<2.62	24.60	55.50	20700.00	183.00	10000.00	3090.00	<26.2
012	<3.42	21.20	55.50	19900.00	<68.50	9930.00	788.00	<34.2
013	<3.60	25.90	66.20	26800.00	<71.90	13300.00	1100.00	<36.0
014	<2.79	25.10	62.60	21500.00	223.00	14000.00	799.00	<27.9
015	<2.81	20.80	48.90	21700.00	126.00	11500.00	876.00	<28.1
016	<1.75	25.30	54.40	17500.00	115.00	13200.00	624.00	<17.5
017	<2.31	20.80	44.90	15300.00	101.00	9860.00	616.00	<23.1
018	<2.01	19.70	37.30	16400.00	<40.20	12800.00	763.00	<20.1
019	<4.06	19.50	57.70	20400.00	<81.30	11000.00	774.00	<40.6

Table 2 (con't). Trace metal and total PAH concentrations (ppm, dry weight) in sediment samples, Long Meadow Lake, Minnesota Valley National Wildlife Refuge, Minnesota, August, 1988.

Sample No.	Ni	Ag	Sr	Sn	V	Zn	Total PAHs
001	15.90	<16.6	36.80	<16.60	28.10	171.00	31.45
002	30.70	<28.40	71.00	<28.40	31.80	349.00	36.71
003	<21.60	<27.00	62.20	<27.00	40.00	306.00	43.75
004	30.30	<32.30	83.20	<32.30	47.70	344.00	25.20
005	28.30	<26.20	64.90	<26.20	45.50	307.00	27.28
006	27.90	<24.90	71.60	<24.90	52.20	319.00	14.95
007	24.90	<21.80	59.80	<21.80	48.50	146.00	8.96
008	20.20	<12.20	57.80	<12.20	28.30	280.00	12.41
009	<25.20	<31.40	76.70	<31.40	39.00	90.60	0.40
010	<20.20	<25.30	93.90	<25.30	41.90	88.40	0.13
011	<20.90	<26.20	78.50	<26.20	29.30	153.00	1.15
012	<27.40	<34.20	79.50	<34.20	<34.20	103.00	3.45
013	<28.80	<36.00	114.00	<36.00	48.90	98.60	0.40
014	<22.30	<27.90	75.40	<27.90	40.20	276.00	31.10
015	<22.50	<28.10	96.60	<28.10	29.80	164.00	5.70
016	21.80	<17.50	52.60	<17.50	41.40	176.00	29.70
017	<18.50	<23.10	69.90	<23.10	36.10	123.00	8.70
018	<16.10	<20.10	83.50	<20.10	32.90	81.50	3.10
019	<32.50	<40.60	91.90	<40.60	<40.60	78.90	0.05

Table 3. The threshold metal and organic compound concentration (ppm, dry weight) presented in two different guidelines for the evaluation of sediment-sorbed contaminants.

	MOE[a]		NOAA[b]		
Chemical Analyte	Lowest Effect Level[c]	Limit of Tolerance Level[d,e]	Effects Range-Low (ER-L)[f]	Effects Range-Medium (ER-M)[g]	Apparent Threhold (AET)[h]
Aluminum	---	---	---	---	---
Arsenic	6.0	33.0	33.0	85.0	50.0
Cadmium	1.0	10.0	5.0	9.0	5.0
Chromium	31.0	110.0	80.0	145.0	---
Copper	25.0	110.0	70.0	390.0	300.0
Iron (%)	3.0	4.0	---	---	---
Mercury	0.2	2.0	0.15	1.3	1.0
Manganese	460.0	1200.0	---	---	---
Nickel	31.0	90.0	30.0	50.0	---
Lead	31.0	250.0	35.0	110.0	300.0
Selenium	---	---	---	---	---
Zinc	120.0	820.0	120.0	270.0	260.0
Total PAHs	2.0	11,000.0	4.0	35.0	22.0

[a] MOE - Ontario Ministry of the Environment (Persaud et al. 1990).
[b] NOAA - National Oceanic Atmospheric Administration (Long and Morgan 1990).
[c] Lowest effect level - level of sediment contamination that can be tolerated by the majority of benthic organisms.
[d] Limit of tolerance level - level of contamination at which pronounced disturbance of the sediment-dwelling community can be expected.
[e] Numbers in this column are to be converted to bulk sediment values by multiplying by the actual TOC concentration of the sediments (to maximum of 10%), (@TOC of 5%, PCB values is 530 x 0.05 or 26.5 ppm).
[f] Effects Range - Low (ER-L) - concentration at low end of range where effects have been observed.
[g] Effects Range - Medium (ER-M) - concentration midway in the range of reported values associated with biological effects.
[h] Apparent Threshold (AET) - concentration above which statistically significant ($P \leq 0.05$) biological effects always occur and, therefore, are always expected.

Table 4. Wet weight concentrations (ug/g) of heavy metal and chlorinated organic compounds in fish from the Minnesota Valley National Wildlife Refuge, 1988.

Analyte	Skin-off Fillets (Pond C)						Whole Fish (Round Lake)			Whole Fish (Long Meadow Lake)	
	Black Bullheads			Green Sunfish			Black Bullheads			Carp	
	#1	#2	#3	#1	#2	#3	#1	#2	#3	#1	#2
Metals											
Al	<2.0	<2.0	4.4	NA*	NA	NA	<2.0	<2.0	<2.0	NA	NA
Ba	<1.0	<1.0	<1.0	"	"	"	2.8	2.3	2.9	"	"
Be	<0.1	<0.1	<0.1	"	"	"	<0.1	<0.1	<0.1	"	"
Bo	<1.0	<1.0	<1.0	"	"	"	<1.0	<1.0	<1.0	"	"
Cd	<0.1	<0.1	<0.1	"	"	"	<0.1	<0.1	<0.1	"	"
Cr	<0.2	<0.2	<0.2	"	"	"	<0.2	<0.2	<0.2	"	"
Cu	<0.5	<0.5	<0.5	"	"	"	1.5	0.8	0.8	"	"
Fe	7.4	8.4	7.4	"	"	"	27.6	22.2	23.8	"	"
Pb	<2.0	<2.0	<2.0	"	"	"	<2.0	<2.0	<2.0	"	"
Mg	238.0	238.0	228.0	"	"	"	270.0	262.0	280.0	"	"
Mn	<0.3	<0.3	0.6	"	"	"	4.2	4.6	4.9	"	"
Mo	<1.0	<1.0	<1.0	"	"	"	<1.0	<1.0	<1.0	"	"
Ni	1.2	<0.8	<0.8	"	"	"	<0.8	<0.8	<0.8	"	"
Ag	<1.0	<1.0	<1.0	"	"	"	<1.0	<1.0	<1.0	"	"
Sr	0.2	0.2	0.3	"	"	"	6.1	4.4	6.4	"	"
Sn	2.3	2.0	2.1	"	"	"	1.6	1.3	1.6	"	"
V	<1.0	<1.0	<1.0	"	"	"	<1.0	<1.0	<1.0	"	"
Zn	5.4	5.4	5.7	"	"	"	16.5	15.0	16.9	"	"

Table 4 (con't). Wet weight concentrations (ug/g) of heavy metal and chlorinated organic compounds in fish from the Minnesota Valley National Wildlife Refuge, 1988.

	Skin-off Fillets (Pond C)						Whole fish (Round Lake)			Whole fish (Long Meadow Lake)	
	Black Bullheads			Green Sunfish			Black Bullheads			Carp	
Analyte	#1	#2	#3	#1	#2	#3	#1	#2	#3	#1	#2
Chlorinated Organic Compounds											
Total PCBs	nd**	nd	nd	nd	nd	nd	0.23	0.27	0.16	nd	1.00
r-chlordane	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.01
t-nonachlor	nd	nd	nd	nd	0.01	nd	nd	nd	nd	0.06	0.01
α-chlordane	0.01	0.01	0.01	nd	nd	nd	nd	nd	nd	0.01	0.02
p,p'-DDE	0.01	0.01	0.01	0.02	0.03	0.01	0.02	0.03	0.02	0.07	0.17
p,p'-DDD	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	nd	0.10	0.11

*NA=not analyzed
**nd=not detected at 0.01 ug/g detection limit

FIGURES

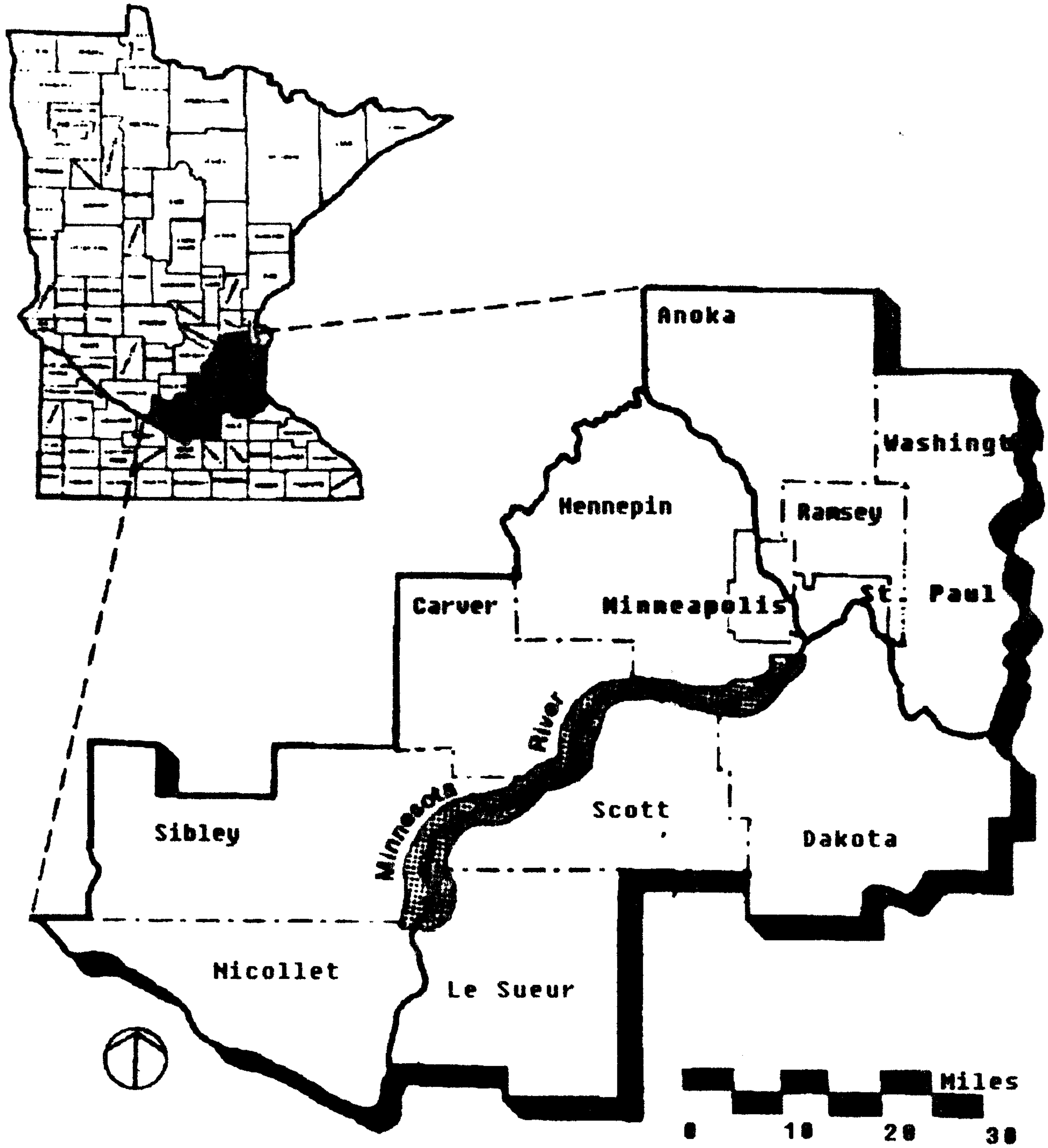

Figure 1. Minnesota Valley National Wildlife Refuge, Minnesota

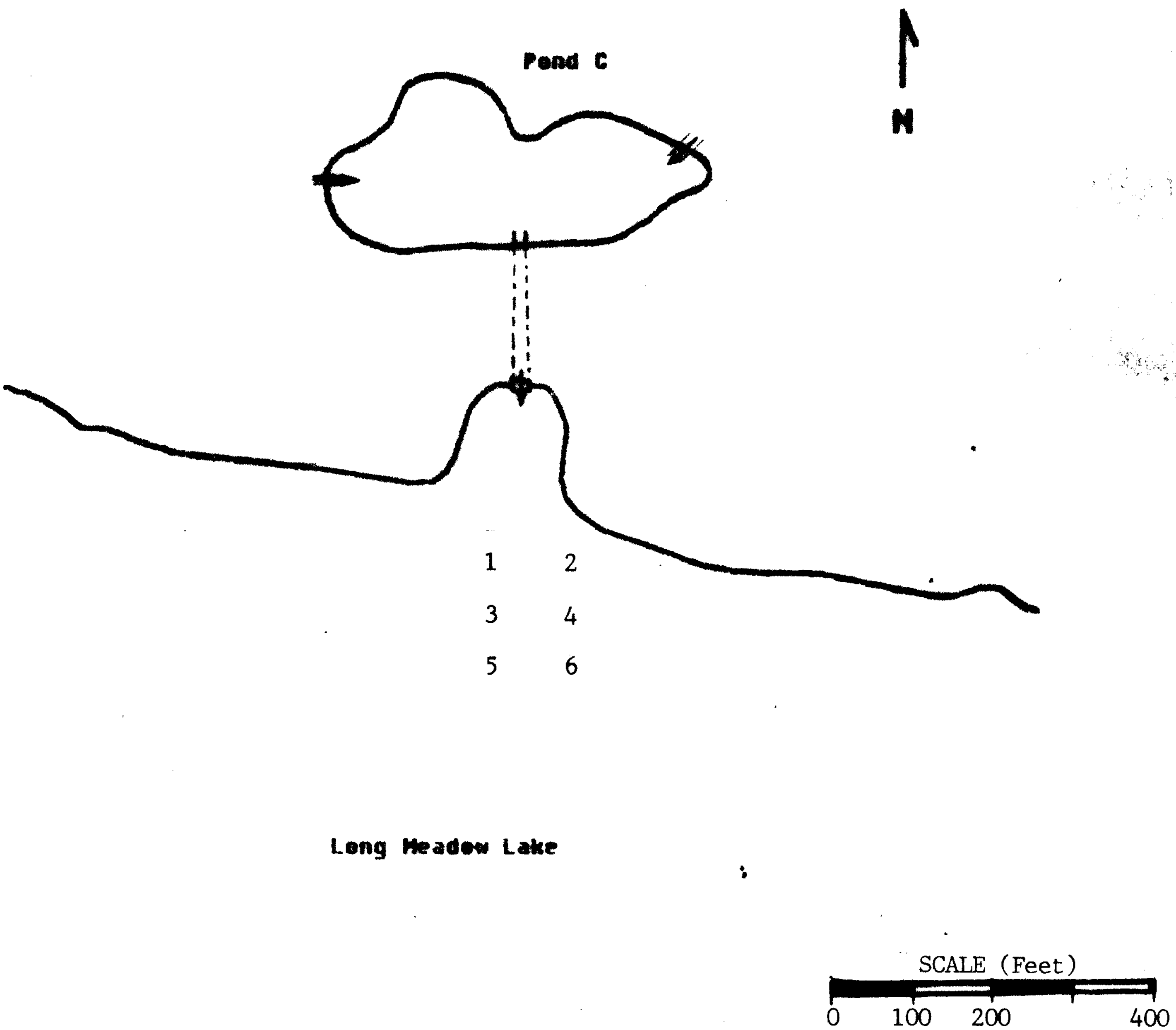

Figure 2. Sediment sample locations within the Pond C discharge zone, Long Meadow Lake, Minnesota Valley National Wildlife Refuge, Minnesota

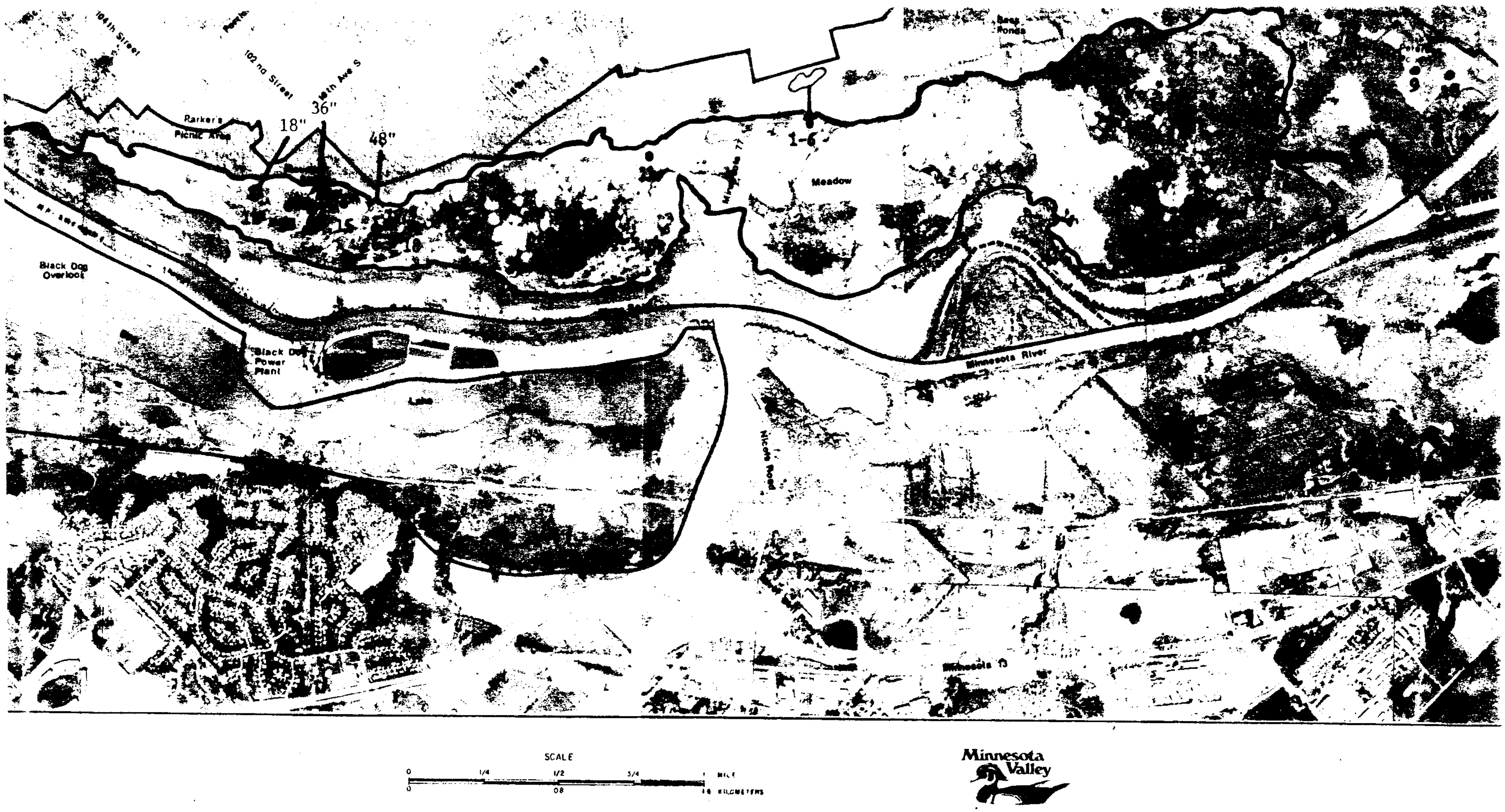

Figure 3. Sediment sampling locations, Long Meadow Lake, Minnesota Valley National Wildlife Refuge, Minnesota

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